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Title:	Least-squares elastic reverse-time migration of microseismic data using inverted moment-tensor sources
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Least-squares elastic reverse-time migration of microseismic data using inverted moment-tensor sources

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Objective

Imaging fracture zones using least-squares reverse-time migration of microseismic data

Outline

- Introduction
- Adaptive moment-tensor joint inversion
- Least-squares reverse-time migration
- Conclusions

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- **Introduction**
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Introduction

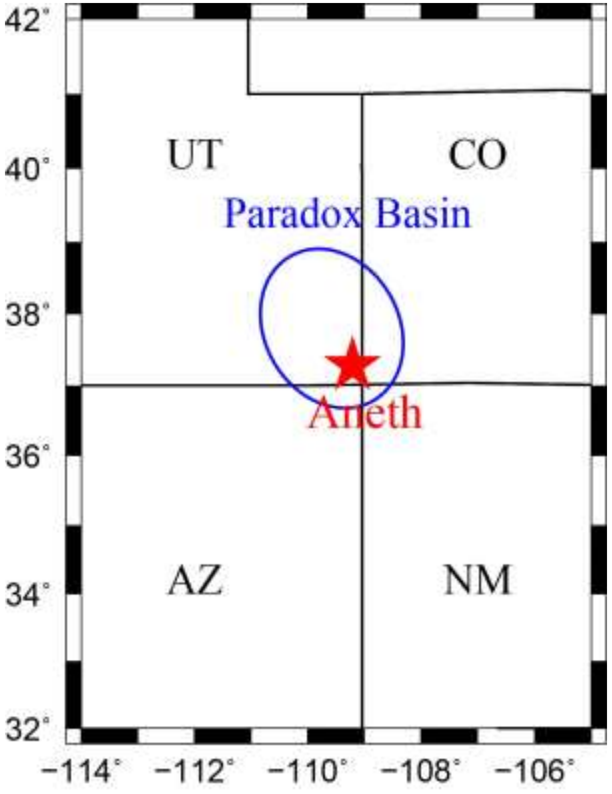
- Monitoring CO_2 reservoirs for long-term storage using induced microseismicity
- Using microseismic data
  - To directly image fracture zones using microseismic data, and
  - To imaging sedimentary layers surrounding microseismic clusters
- Conventional least-squares reverse-time migration using explosive or vector sources cannot match radiation patterns of microseismic data

Introduction

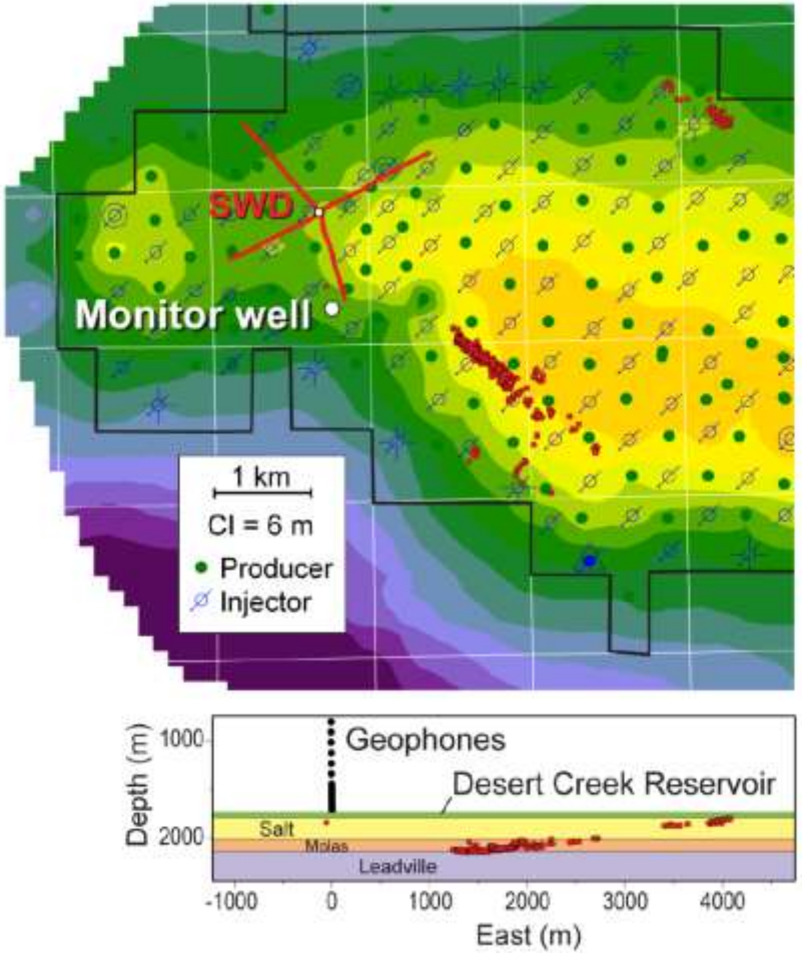
- We recently developed a new method for adaptive moment-tensor joint inversion of microseismic data acquired from a single-borehole geophone array.
- In this work:
  - We employ least-squares reverse-time migration of microseismic data using moment-tensor sources.
  - We apply the method to microseismic data acquired at the Aneth CO_2-Enhance Oil Recovery (EOR) field using single vertical borehole.

The Aneth CO_2-EOR field at Utah

- CO_2 injection from 2007 to 2009
- 23 levels of geophones within a vertical borehole spanning from 800 to 1700 m



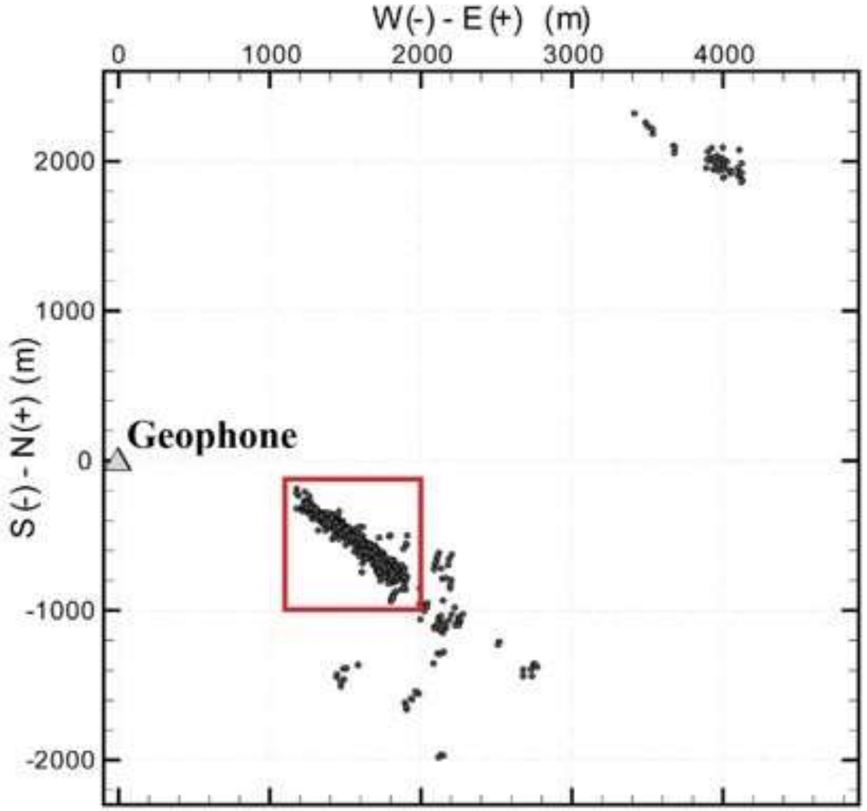
(Soma and Rutledge, 2013)



Aneth CO_2-EOR field

- More than 3000 microseismic events detected from May 2008 to March 2009
- 1266 events were relocated using direct, reflection and diffraction waves

(Soma and Rutledge, 2013)



Outline

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- **Adaptive moment-tensor joint inversion**
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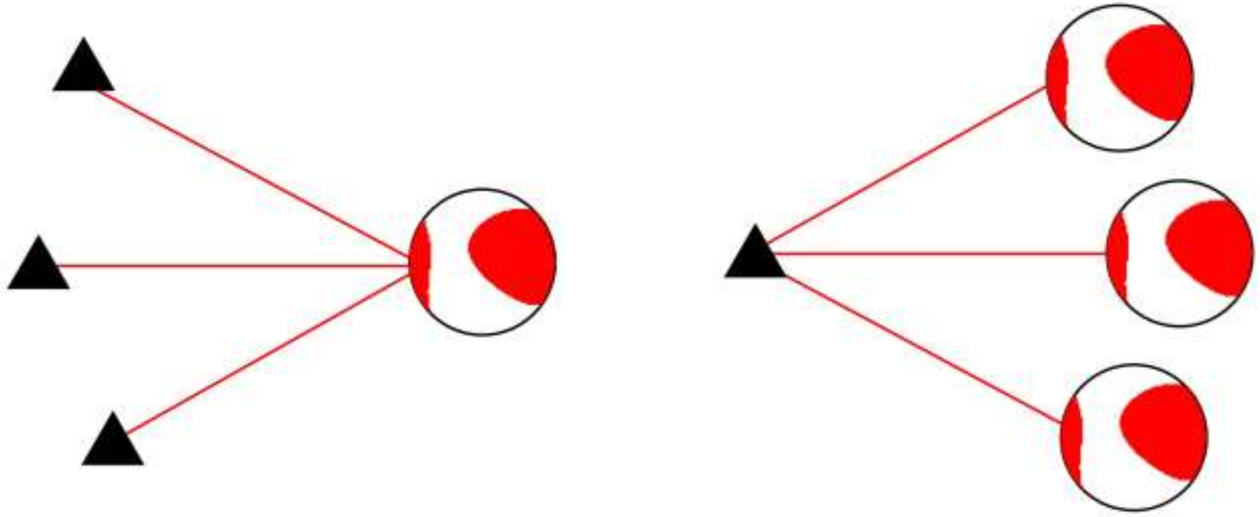
Adaptive moment-tensor joint inversion method and its application to the Aneth CO_2-EOR field

- Uncertainty of moment-tensor inversion with limited azimuthal coverage
- Clustering events with similar seismic waveforms and radiation patterns
- Similar focal mechanisms in the adjacent areas (e.g. Dahm et al., 1999; Rutledge, 2004; Maxwell, 2014)
- Inverting the clustered events with the same focal mechanism



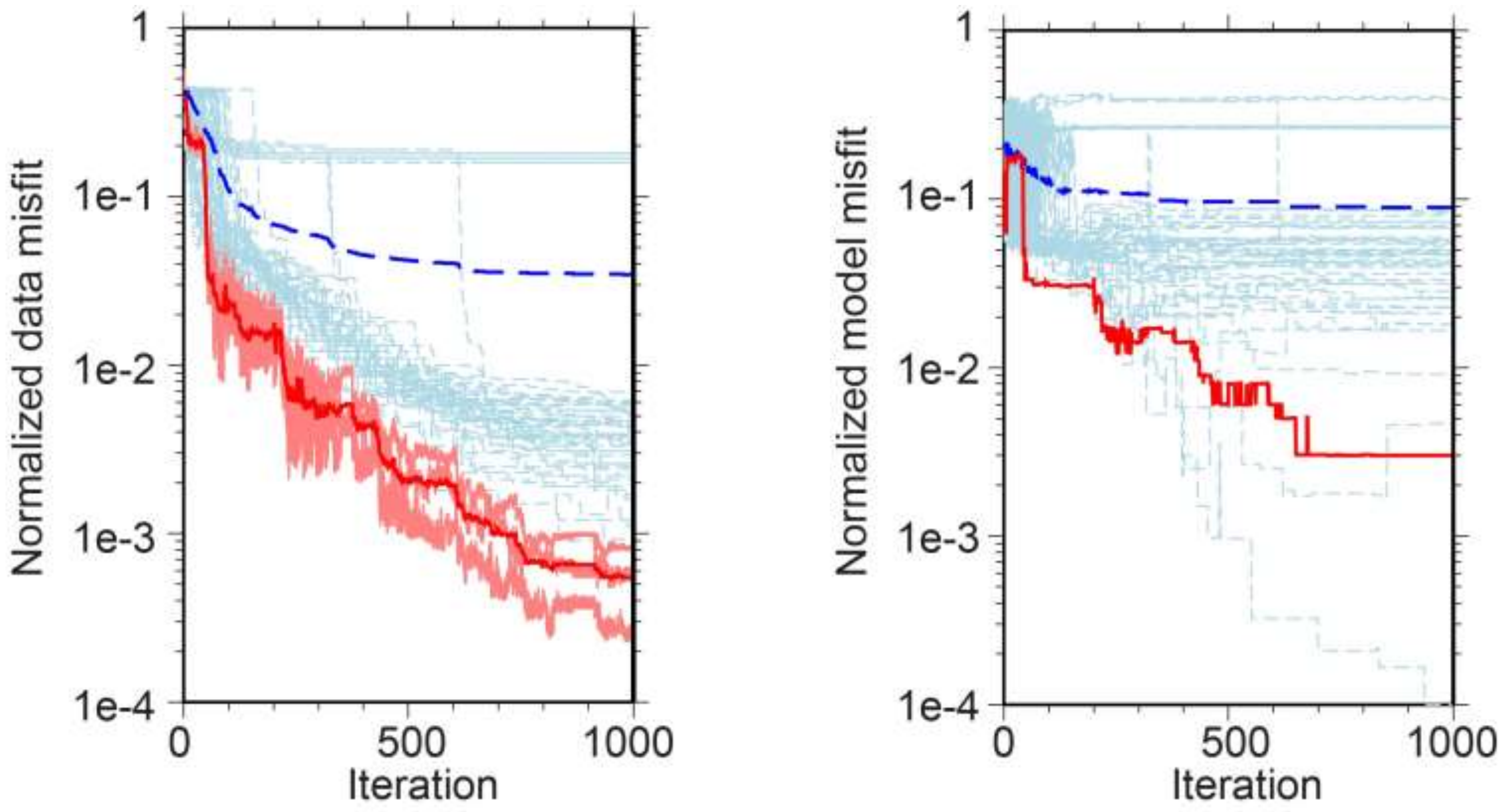
An adaptive joint inversion

- Joint inversion: events in a cluster are inverted using the same focal mechanism (strike, dip, rake, ISO and CLVD) but different source durations and moments
- Adaptive inversion: each event is further inverted based on the joint inversion result with a search range of ±10° for strike, dip and rake, ±0.05 for ISO and CLVD

Synthetic test for joint inversion

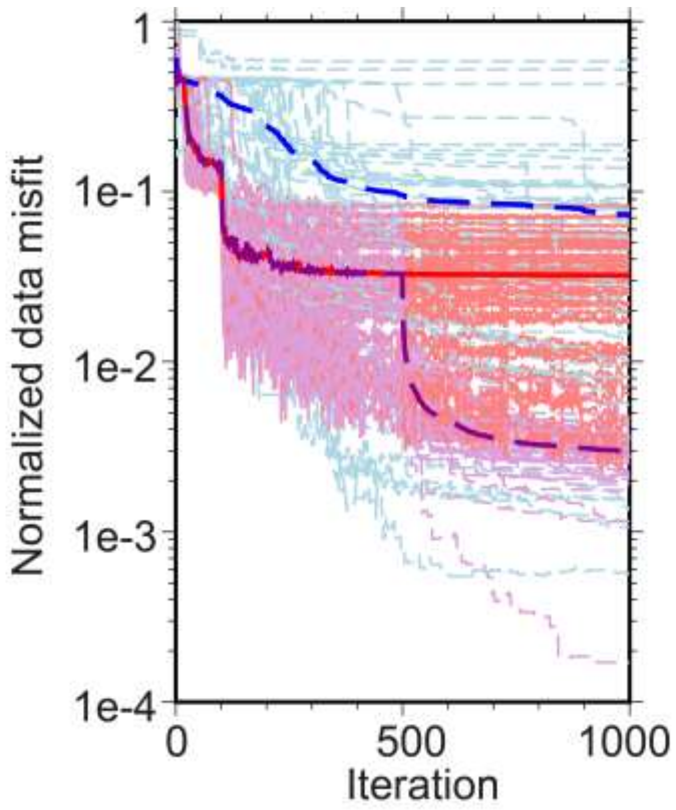
50 events with the same focal: stk:220 dip:45 rake:0 iso:0.1 clvd:0.2

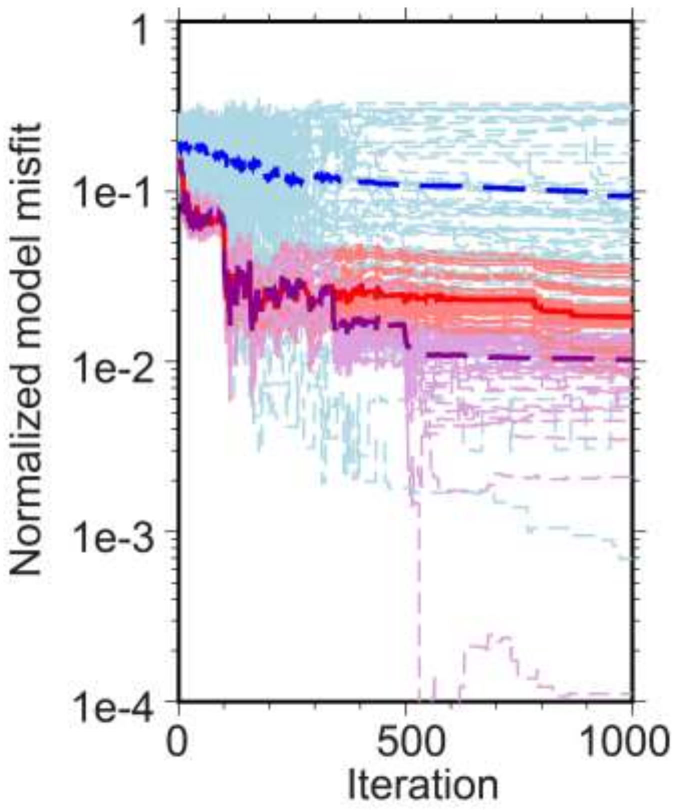
Same configuration as the Aneth field



Adaptive joint inversion with varying focal

50 events with varying focals: stk:220 dip:45 ± (up to 10) rake:0 iso:0.1 clvd:0.2

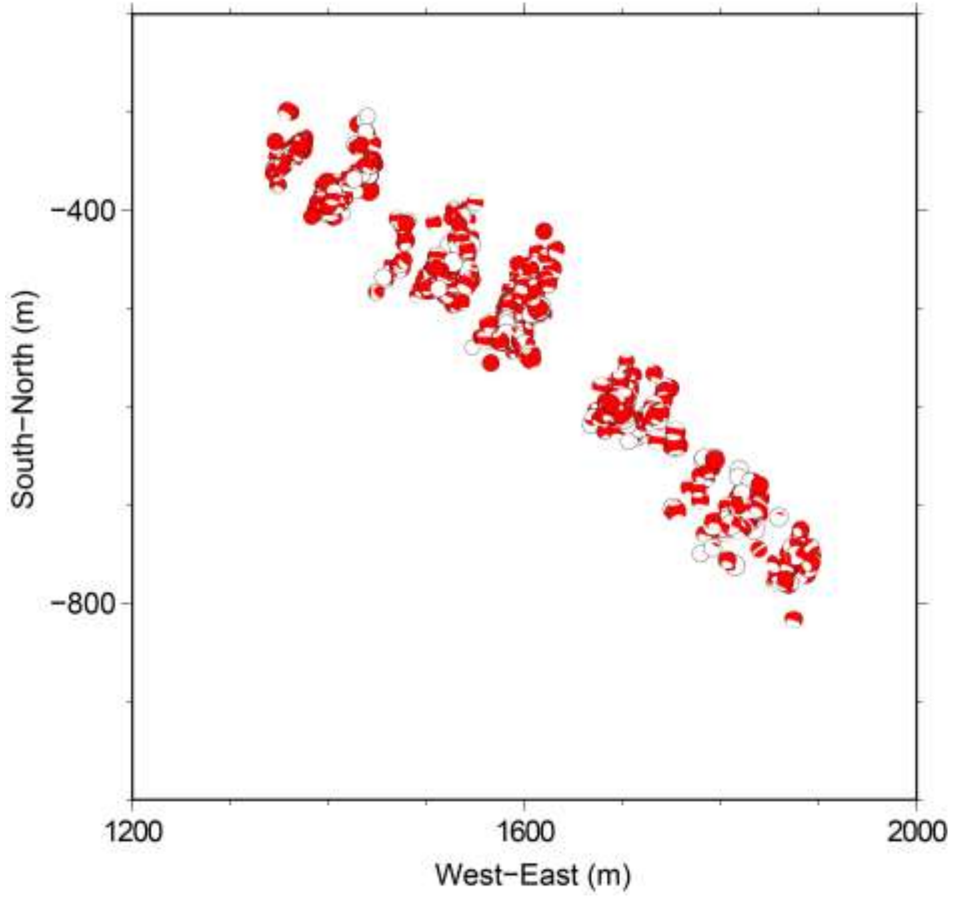


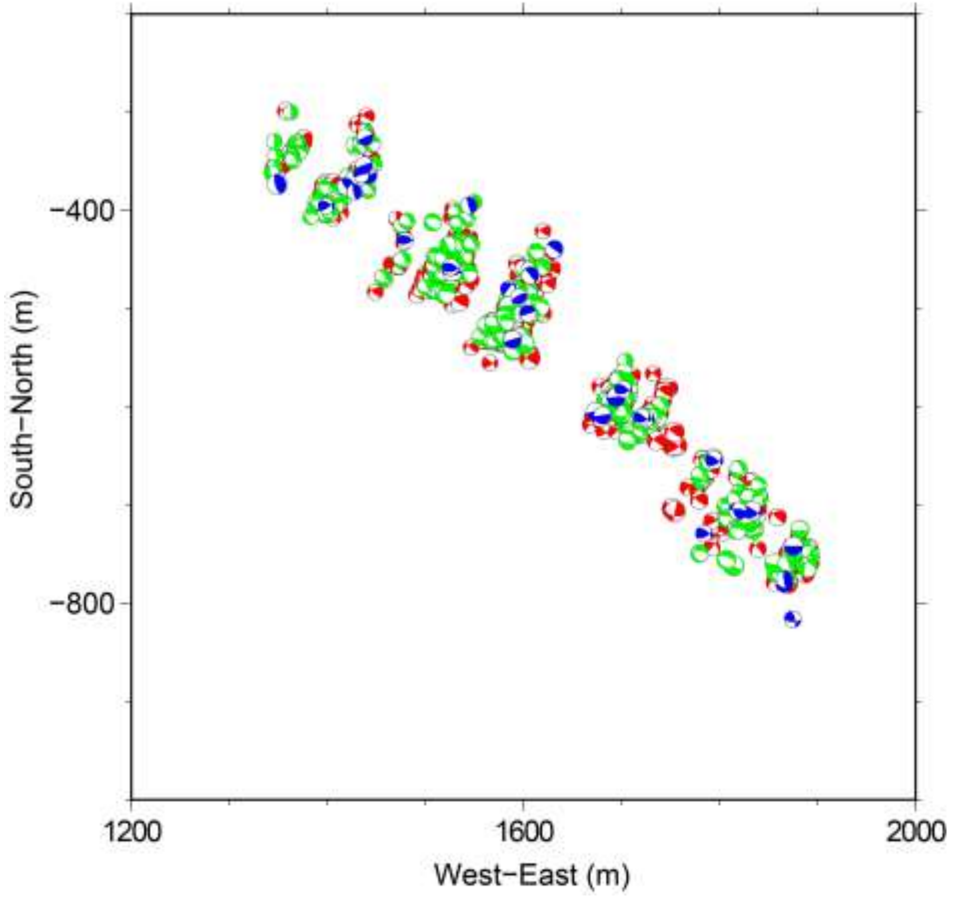


Individual inversion

Left: full moment tensor

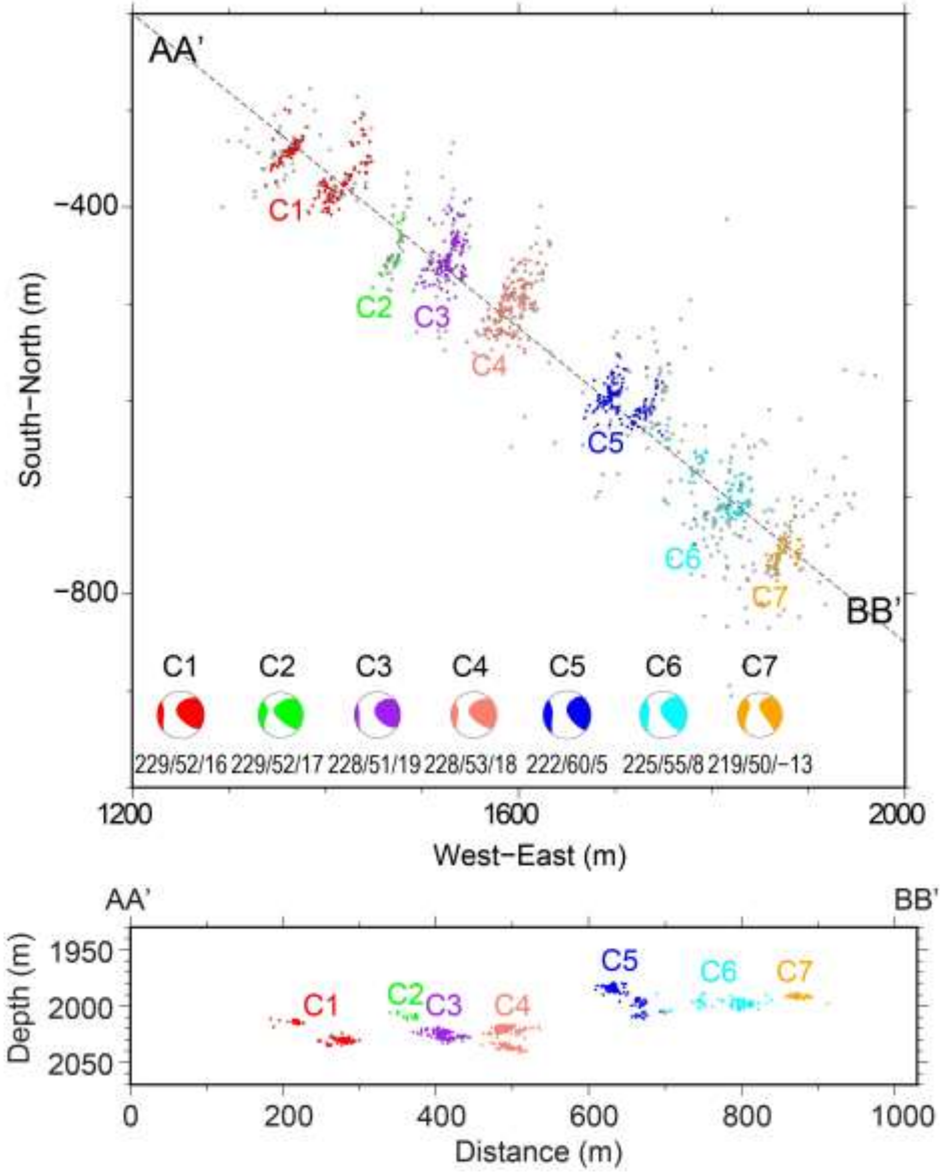
Right: double couple only



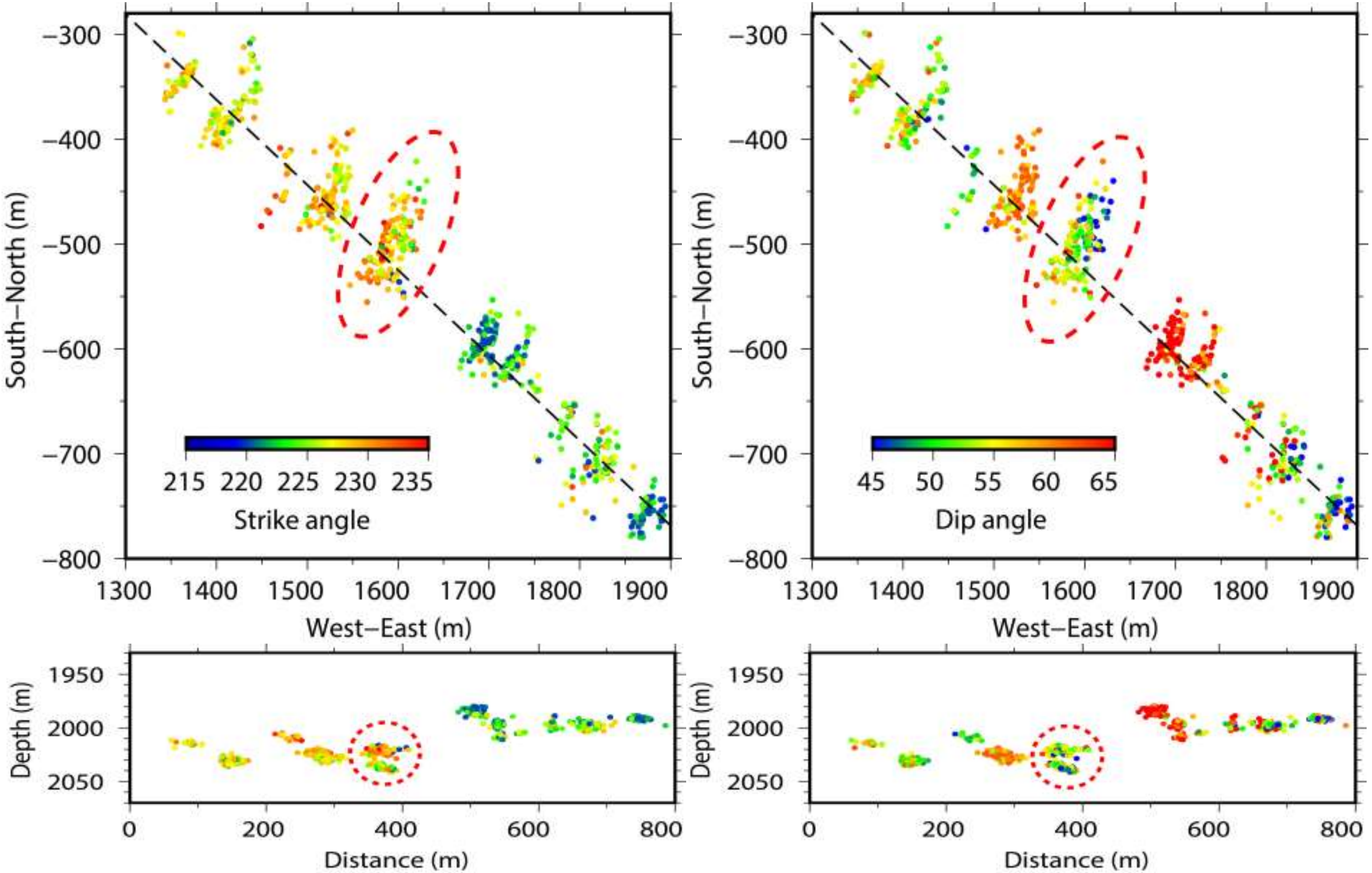


Joint inversion result

- Seven clusters based on similarities of microseismic waveforms and radiation pattern
- Consistent but slightly varying focal mechanisms of the seven clusters
- Large non-double couple component



Adaptive inversion result



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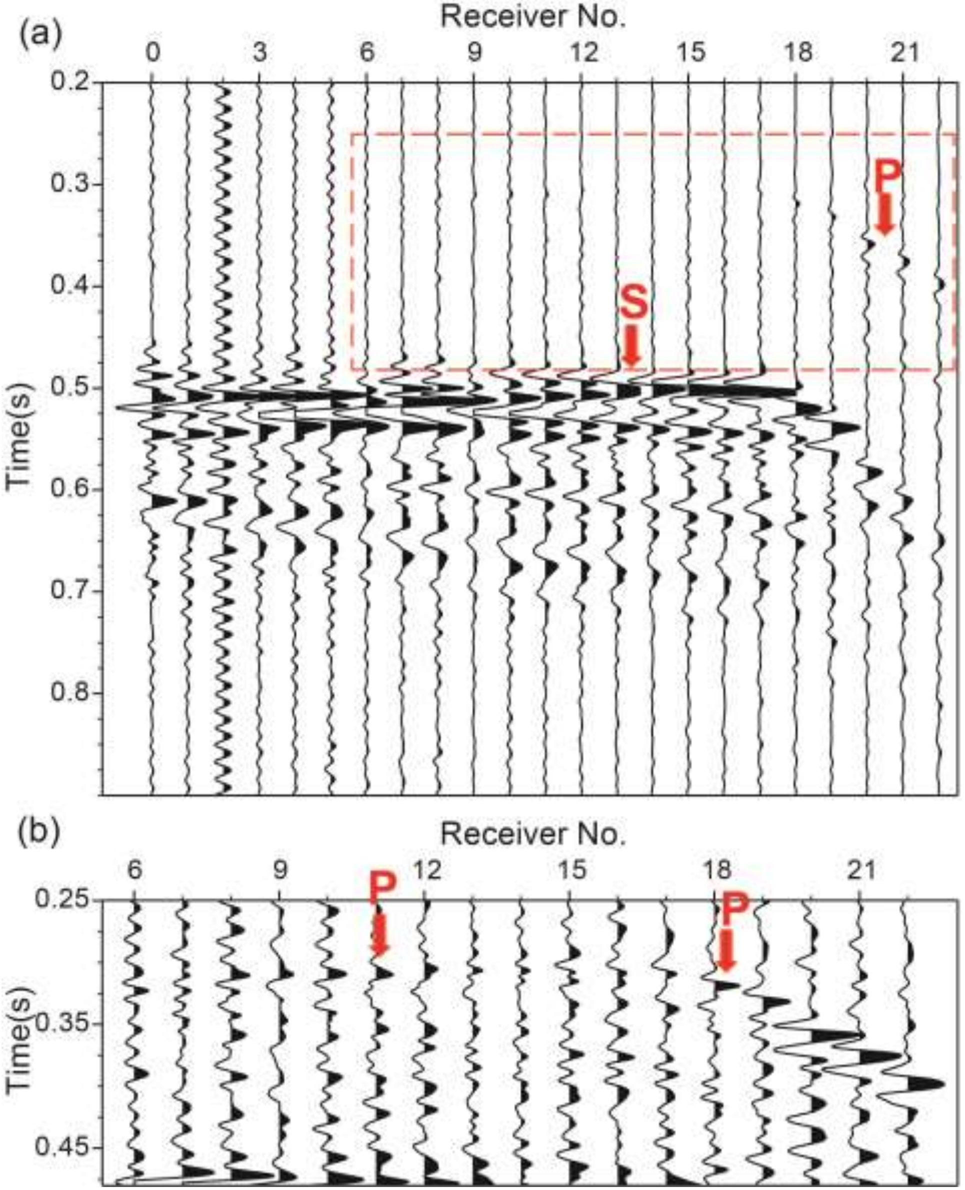
Least-squares reverse-time migration of microseismic data using inverted moment tensors

- Explosive source cannot make use of the strong S waves
- Explosive and vector source cannot match the radiation pattern of microseismic source



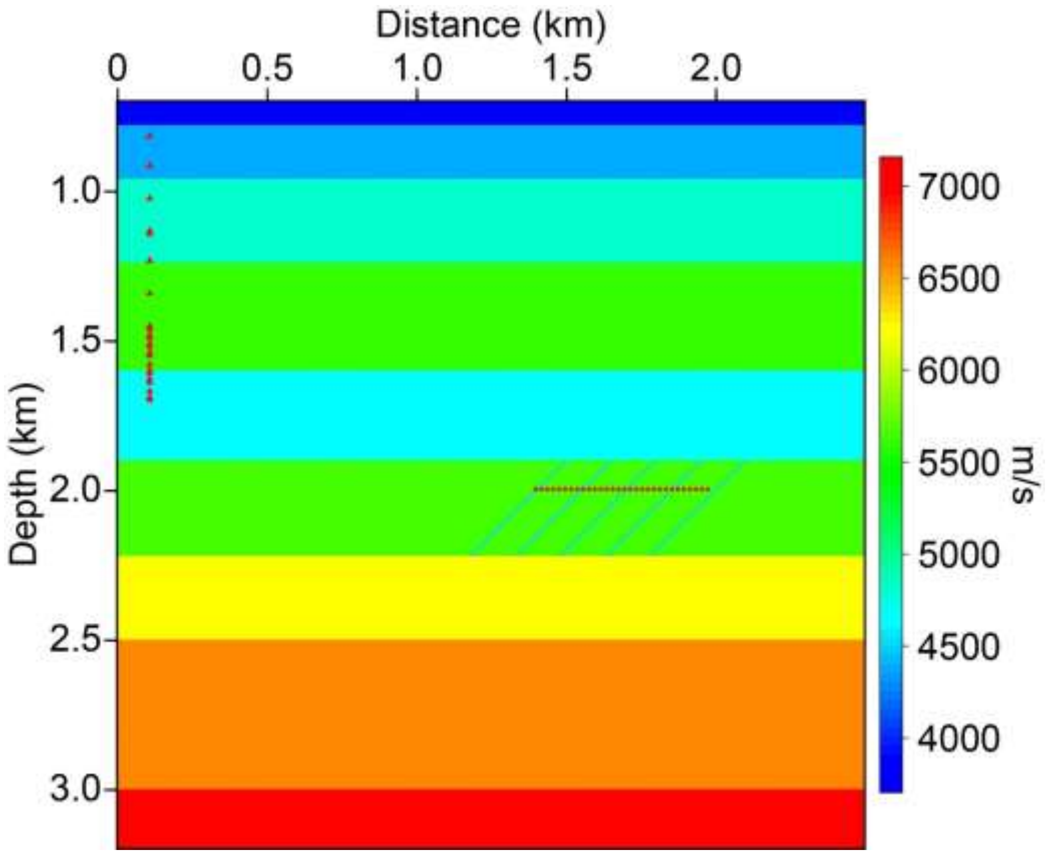
Moment-tensor source in finite difference

- Add the moment tensor as the stress in waveform modeling

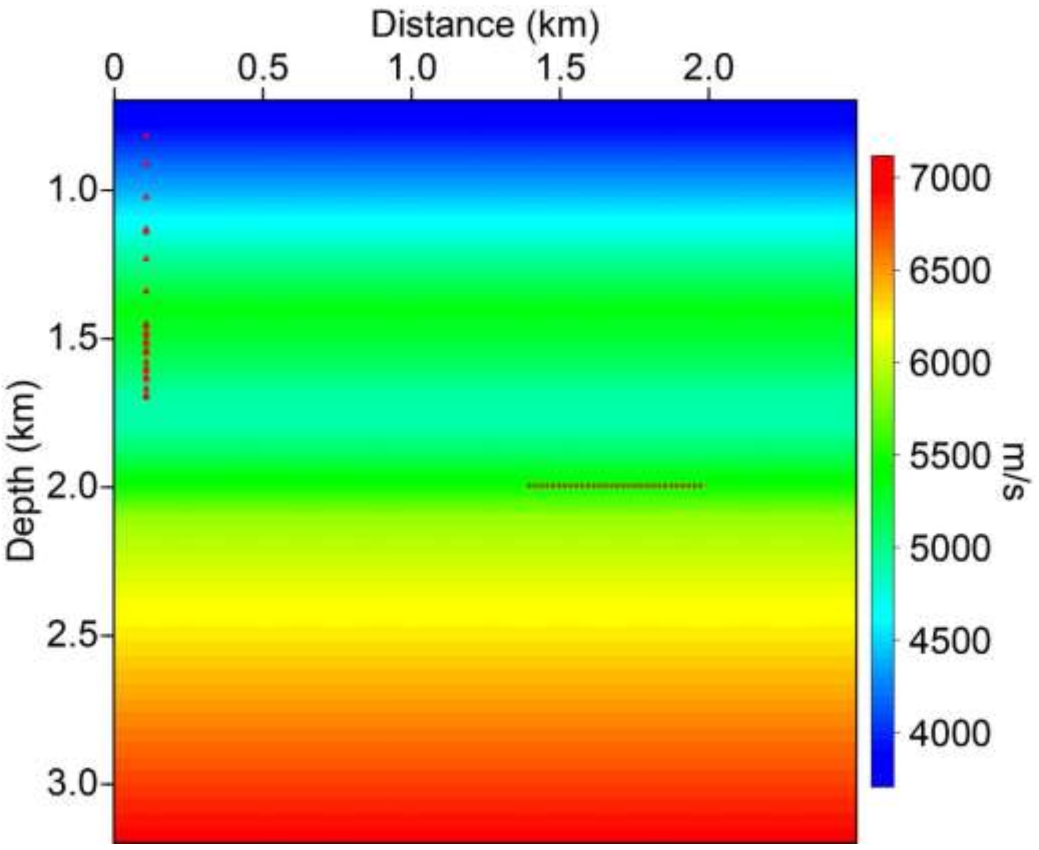
$$\sigma_{ij} = \sigma_{ij} + \frac{\Delta t M_{ij}(t)}{V}, i = 1,3, j = 1,3$$

Synthetic test

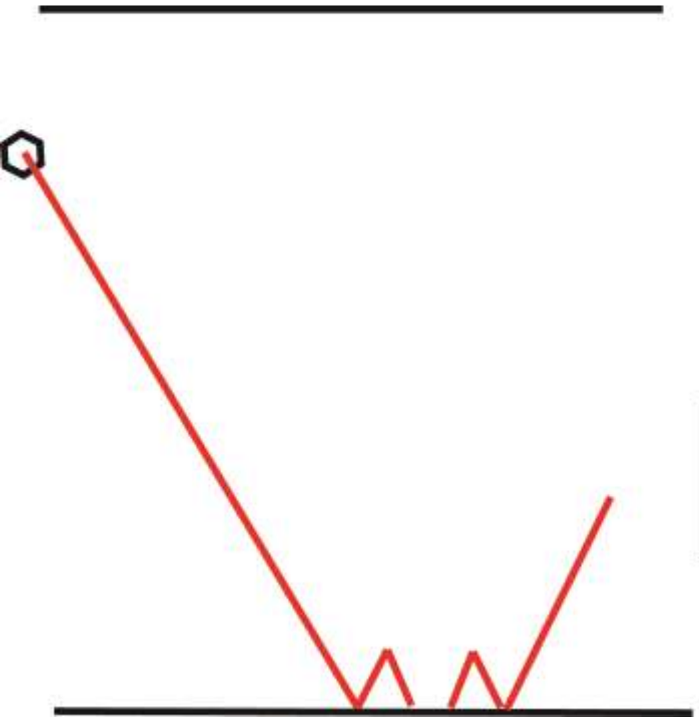
True model



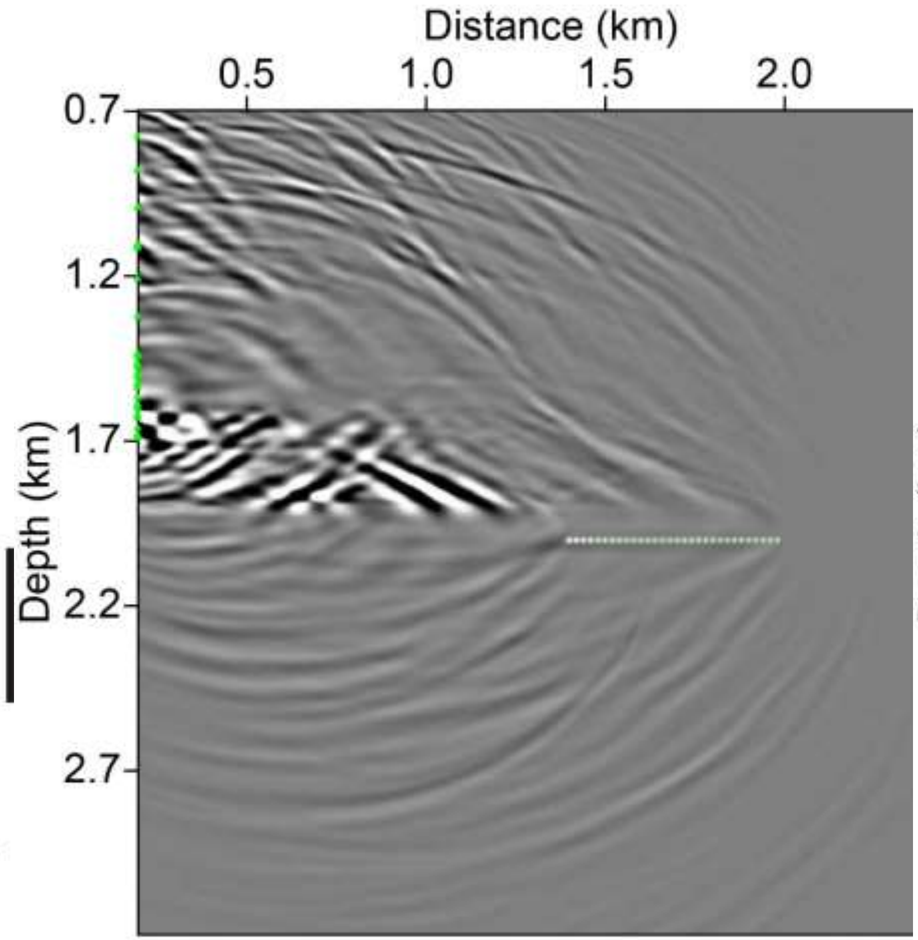
Smooth model



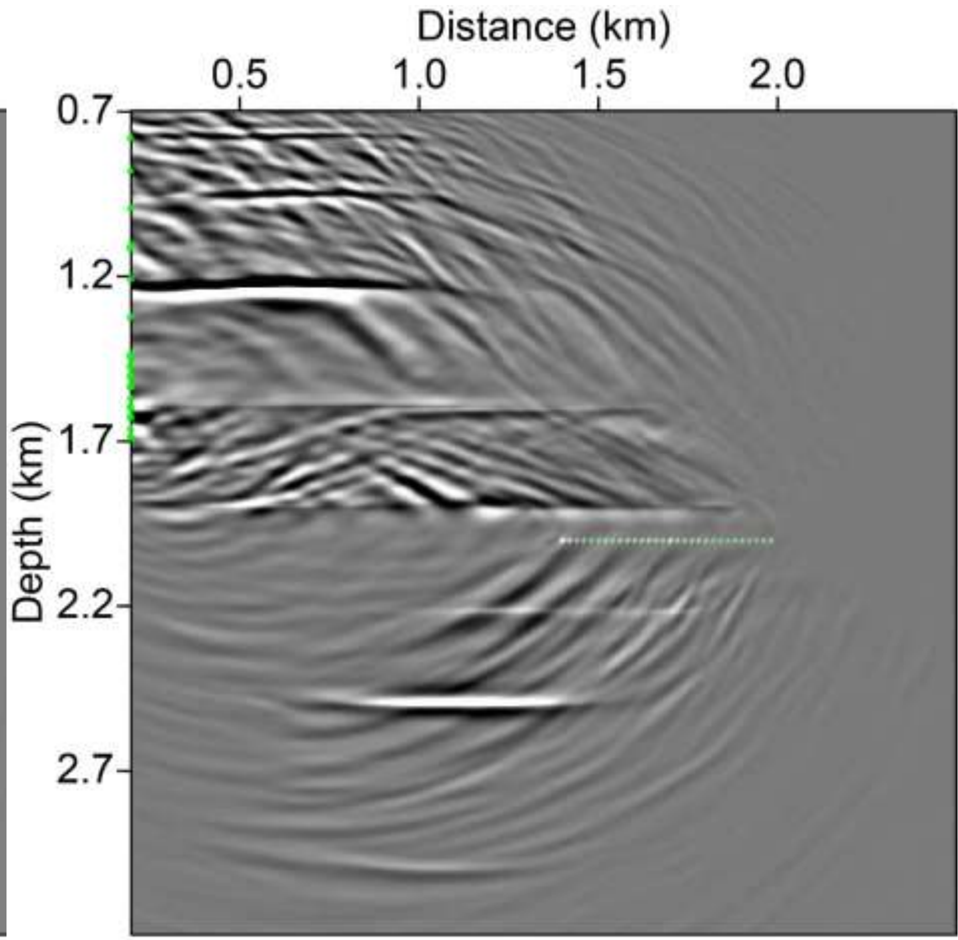
Up and Down going wavefield



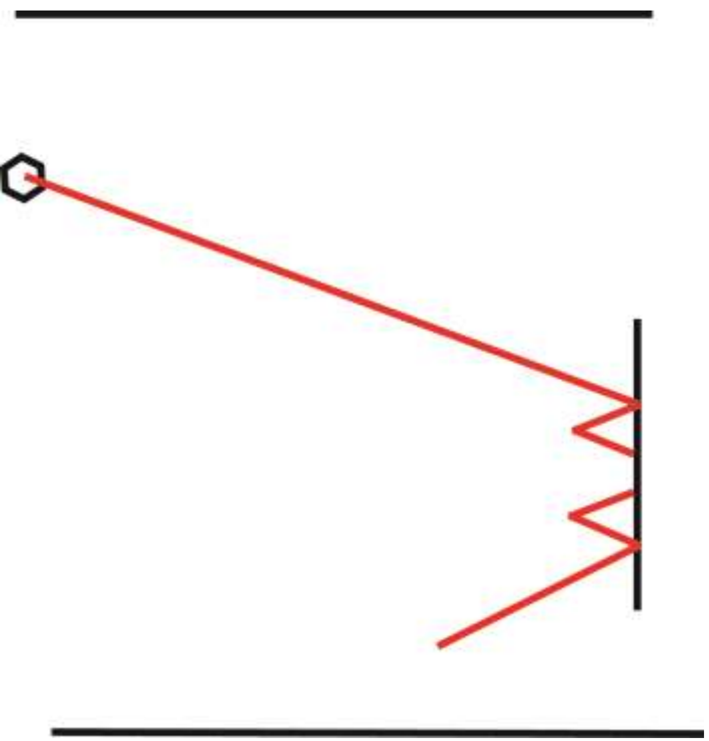
Explosive sources



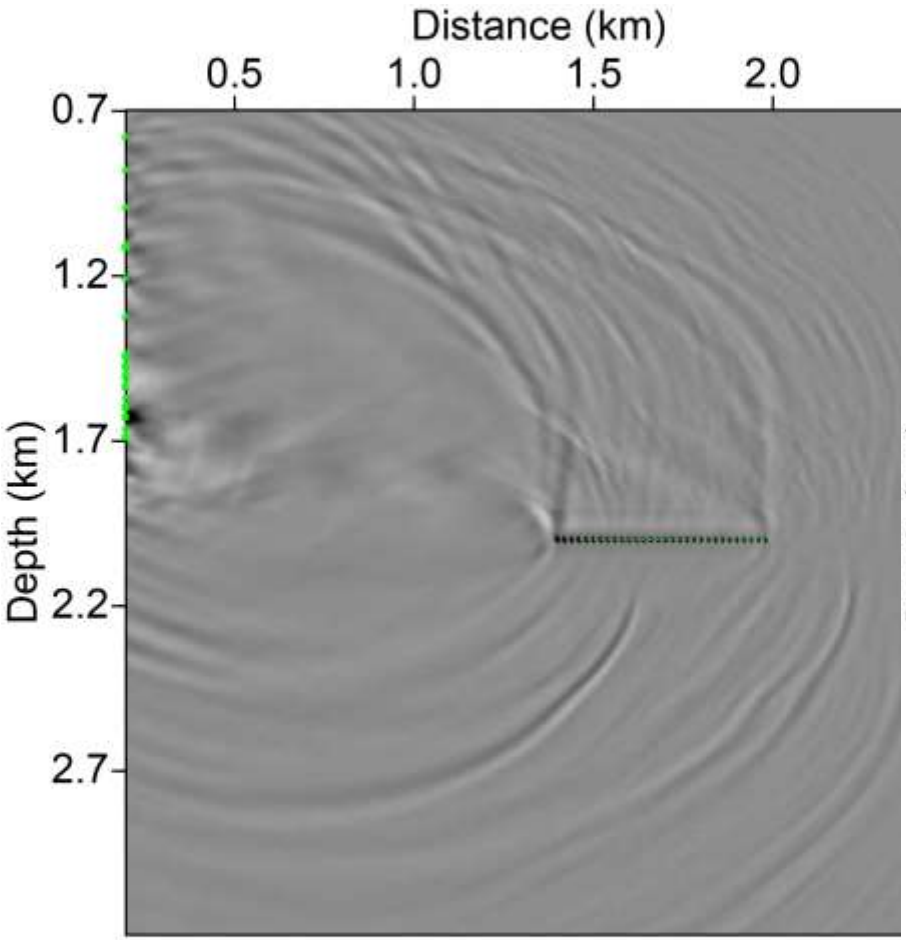
Moment-tensor sources



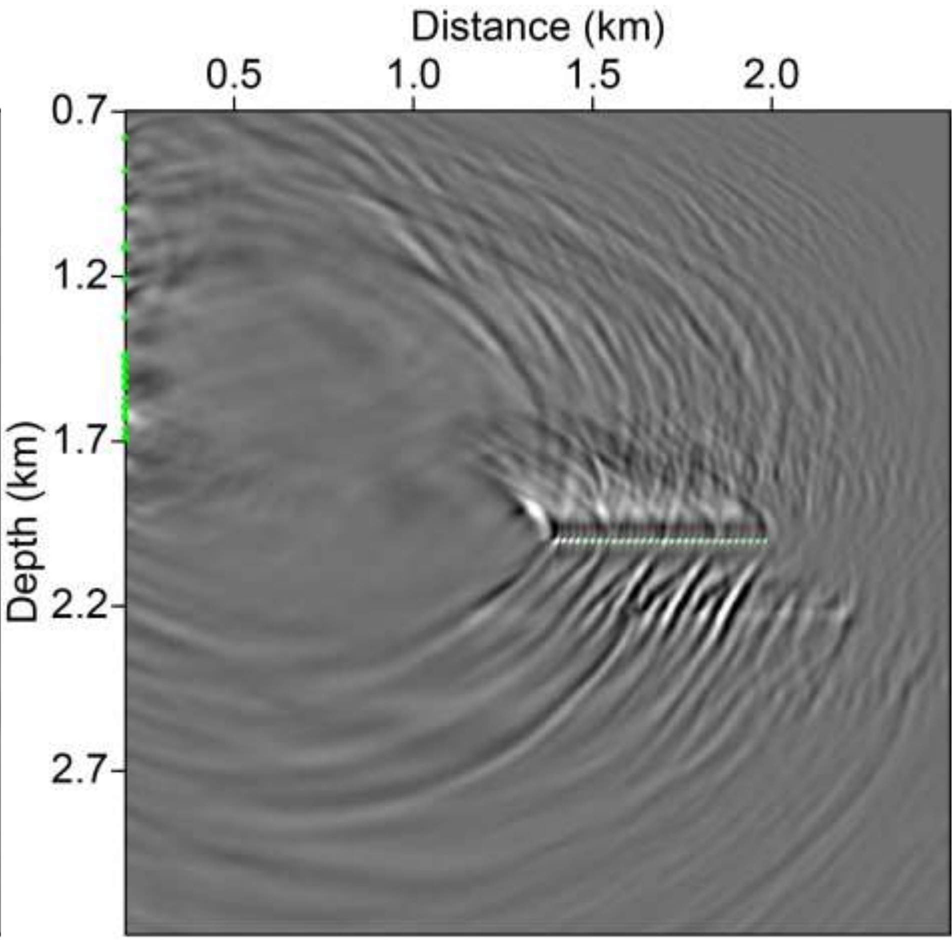
Right going wavefield



Explosive sources

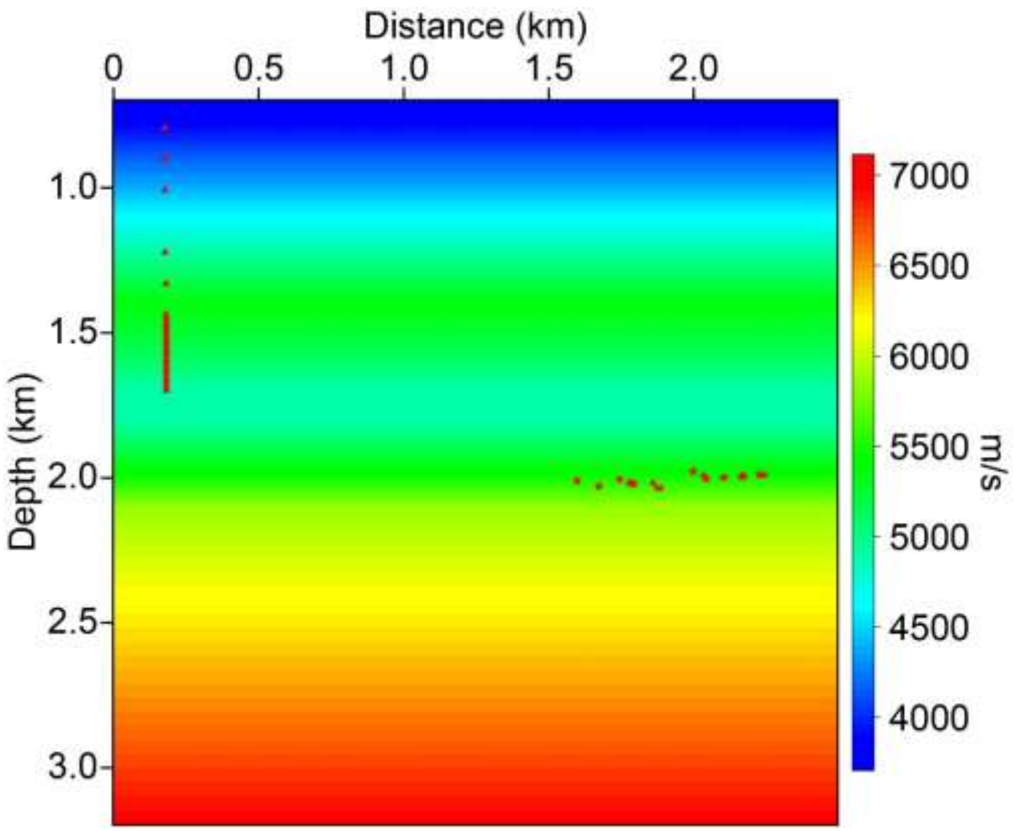


Moment-tensor sources



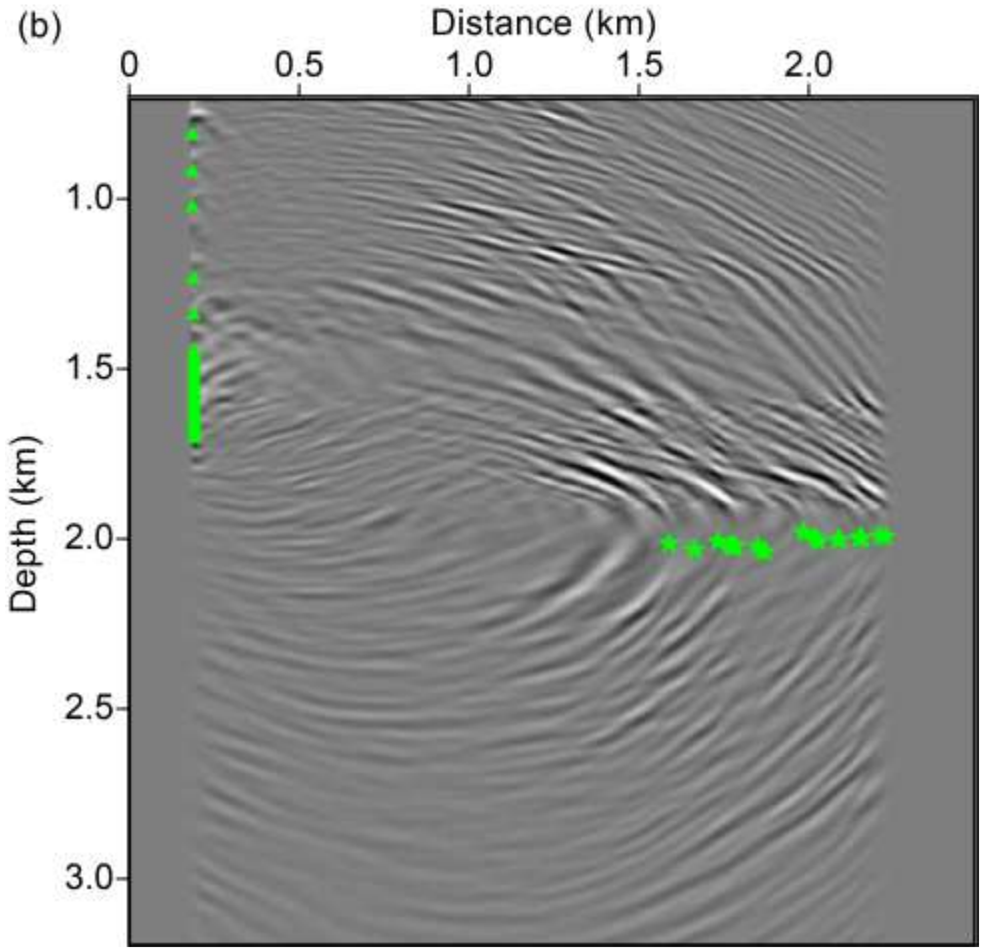
Application to the Aneth field

- Selecting 38 microseismic events from the seven clusters
- Forming a 2D line
- Performing the imaging in a 3D model

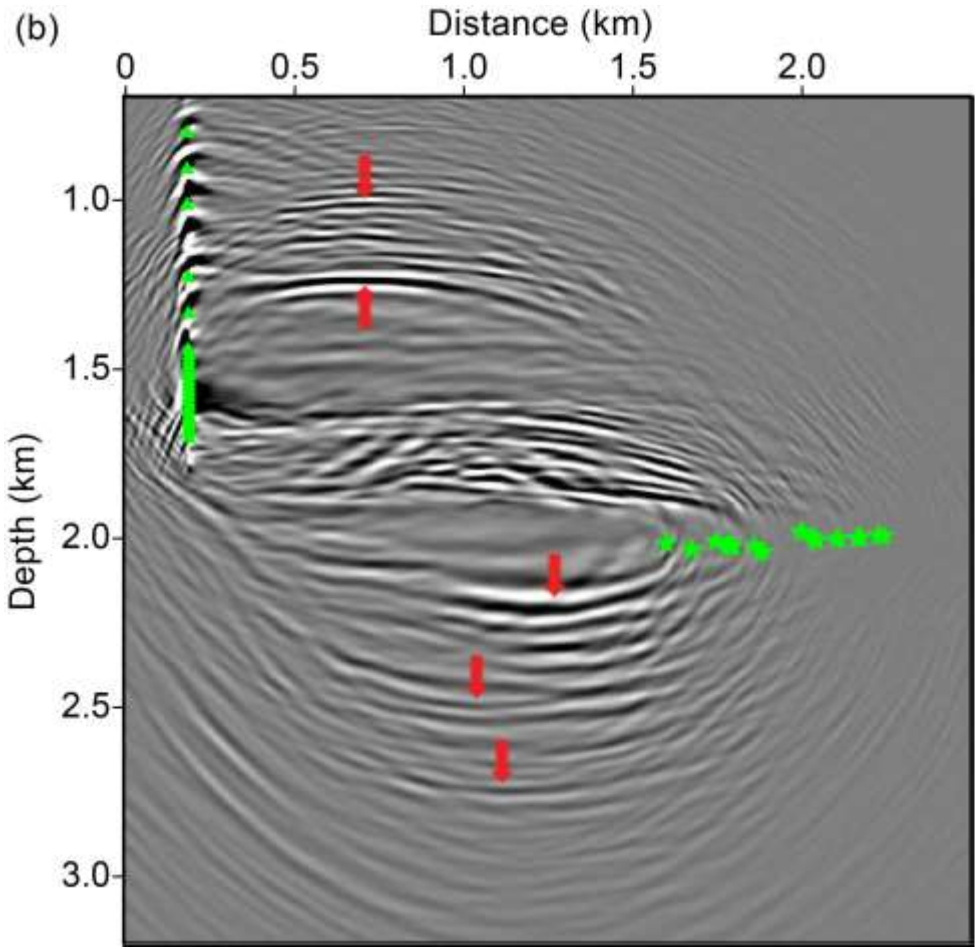


Up and Down going wavefield

Explosive sources

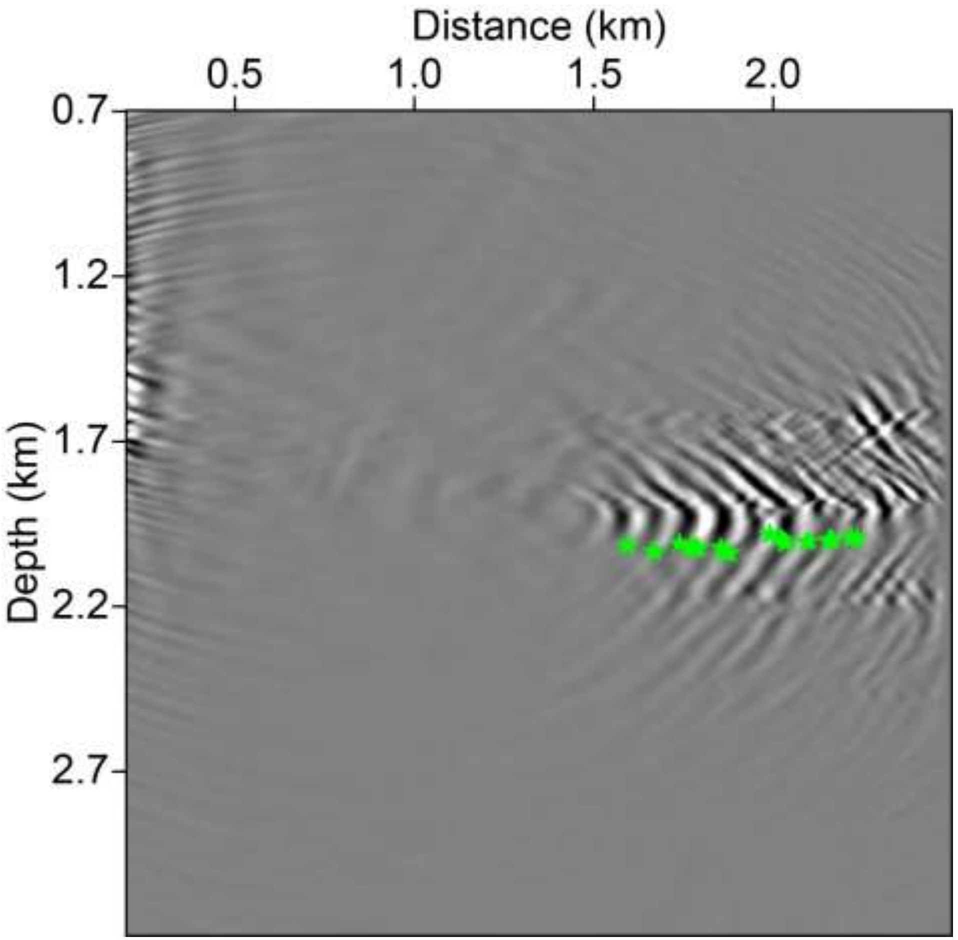


Moment-tensor sources

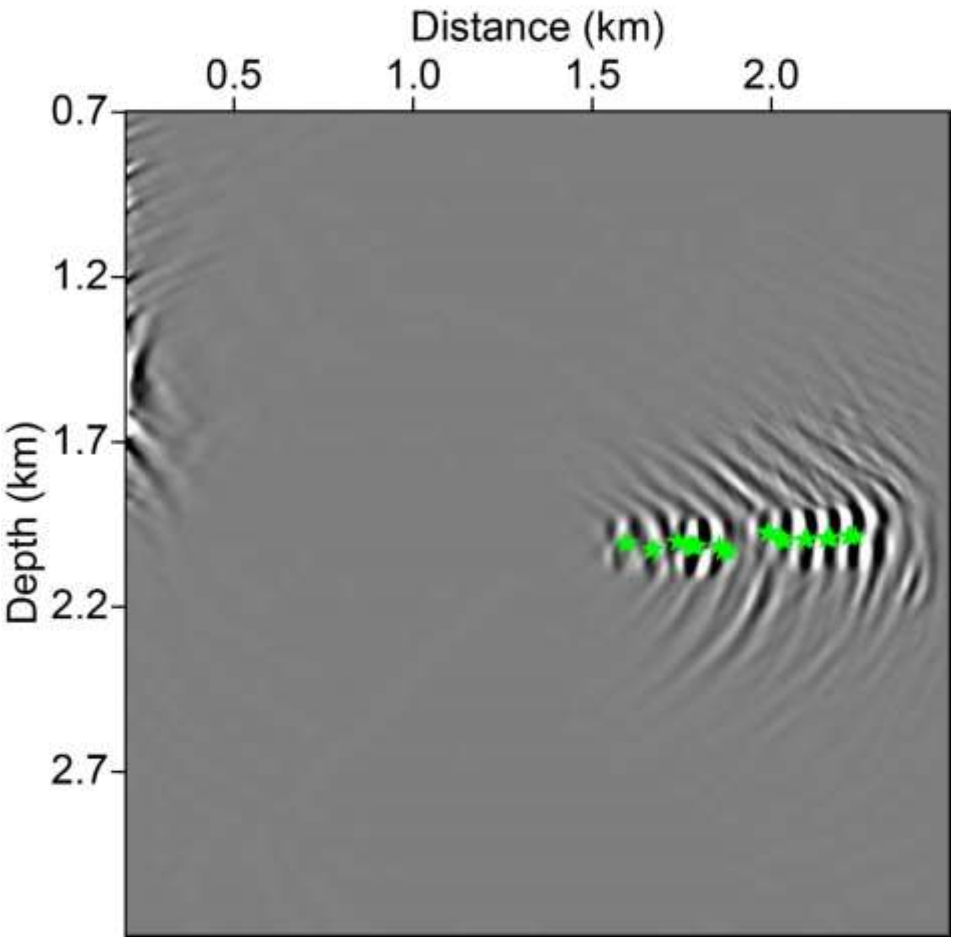


Right going wavefield

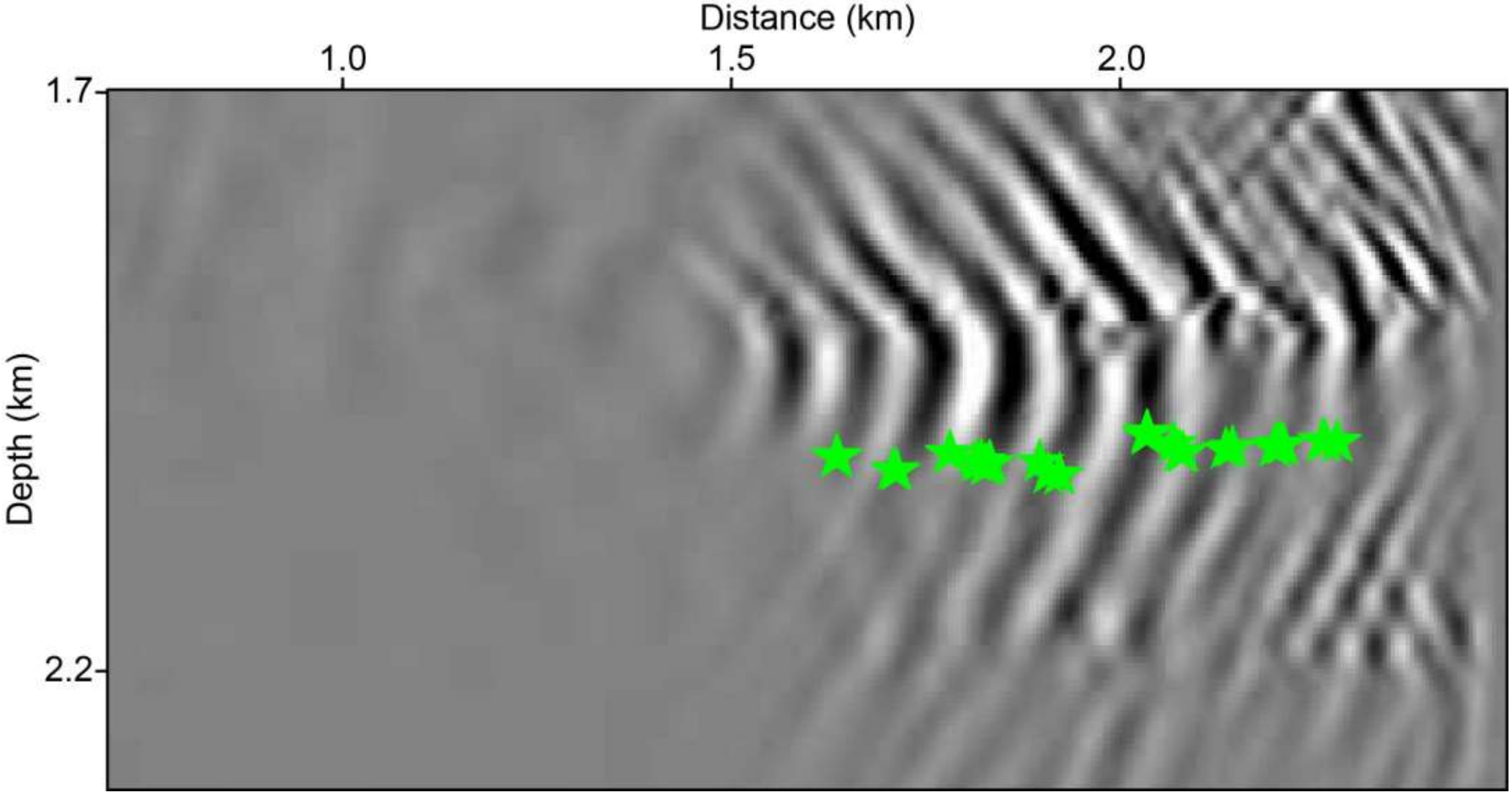
Explosive sources



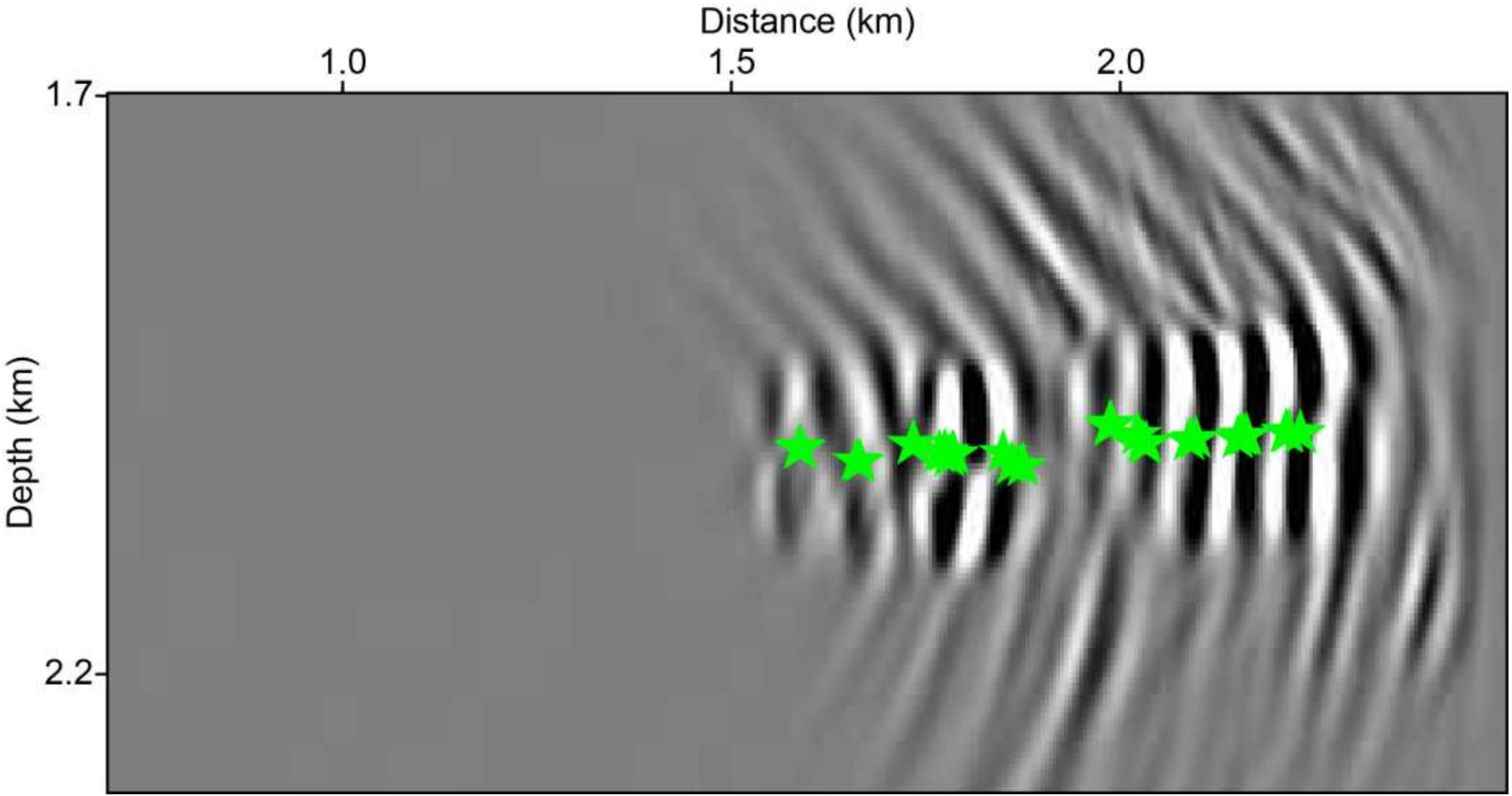
Moment-tensor sources



Explosive sources



Moment-tensor sources



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Conclusions

1. Developed an adaptive moment-tensor joint inversion method and applied to the Aneth field
   - The joint inversion inverts clustered events with the same focal mechanism
   - The adaptive inversion inverts each event in a search range around the joint inversion result

2. Developed a least-squares reverse-time migration algorithm for microseismic data
   - Image facture zones around microseismic clusters
   - Image several sedimentary layers above and beneath the sources
   - Need to use moment-tensor sources to produce correct migration images

Acknowledgements

- The work was supported by the U.S. Department of Energy through contract DE-AC52-06NA25396 to Los Alamos National Laboratory.
- The computation was performed using the super-computer resources of LANL's Institutional Computing Program.

Thank you for your attention!